LIBRARY
OF THE
MASSACHUSETTS INSTITUTE
OF TECHNOLOGY

MASS. INST. TECH.
JUN 20 1966
DEWEY LIBRARY

CRITICAL DECISIONS IN THE INITIATION OF DEVELOPMENT PROJECTS

Irwin M. Rubin and Donald G. Marquis

June 1966 #192-66

The research has been supported by a grant (NsG235) from the National Aeronautics and Space Administration.

HD28
.M414
no. 192-66

ECEIVED
JN 29 1966

INTRODUCTION

Many factors occur during the life of a government sponsored research and development project which could have a direct bearing upon the quality of the final product. Looking at a project chronologically, however, there are a number of decisions which occur prior to the time that work actually begins which might have an impact on final performance.

This report[1] will deal with the direct impact on total performance of certain decisions occurring prior to the start of the project. On the government side, decisions as to the type of contract (sole source or competitive) and constraints on the choice of subcontractors will be examined. Within the company, the focus will be on the criteria for selection of project personnel, the percent of total effort subcontracted, and certain characteristics of initial cost and schedule estimates.

Focusing on initial conditions does not imply that other factors, whose time frame spans the entire project, are unimportant. Nor does it eliminate the possibility that an initial decision might affect final performance indirectly by influencing the contractor's decision as to the best form of project to adopt.[2] The rationale is that many

---

[1] Only a fraction of the data collected during the past three years in a broad study of project management will be discussed. Participating in this investigation as research associates and assistants have been J. Randall Brown, Michael Gold, Arthur J. Hansen, Kenneth R. Hootnick, Richard B. Maffei, James E. Mahoney, Robert L. Pearson, Jean-Paul Richard, and David Straight Jr.

[2] See Marquis and Straight (1965) for a comparison of the effectiveness of different forms of project organization.

of the problems which arise during the life of a project are less subject to control by both the government and the contractor than the initial decisions to be examined in this paper.

Research Methods

A project, carried out by a company under contract with a government agency, has many advantages as a unit of study in the investigation of effective performance of research and development. Such a project has a defined beginning and end, it has initial cost and schedule estimates as well as a work statement of technical requirements, and it has separate and audited financial accounting.

Projects were selected on the basis of three criteria:

1. All were R&D contracts awarded by a government agency (or industry prime in several cases) to an industrial firm.
2. All were over $1 million in total value (excluding follow-on production work).
3. All were very recently completed or rapidly nearing completion.

Projects were located in two ways. Alternate firms in the list of 100 largest defense and space firms were invited to cooperate, and if they were willing, a division laboratory was randomly selected, and its most recently completed (or terminated) project became the target of study. The other source was a government contracting agency, in which one or more projects were chosen randomly from those most recently completed.

Information on each project was obtained from five sources: the laboratory manager (LM), the project manager (PM), the government technical monitor (GTM), the government contract administrator (GCA), and the company contract administrator (CA). Judgments of successful performance and a statement of their criteria for evaluating successful performance were obtained from the first four. The laboratory and project manager described the organization and operations of the project group. They and the technical monitor also provided information on success in meeting schedule deadlines and cost criteria. Administrative performance was described by the contract administrators in both the company and the government agency. The questionnaires used in this study were developed on the basis of published literature and of interviews with experienced project managers, and were pretested on approximately 20 projects.[1]

Characteristics of the Projects

Although a total of 48 projects were studied, inevitable difficulties in securing some of the desired information resulted in incomplete records in several cases. In 75% of the cases the records are complete (LM, CA, PM, GTM, and GCA). Incomplete information results primarily from an inability to interview either the LM, GTM, or the GCA.

---

[1] See Marquis and Straight, (1965) for further details.

The projects studied were funded by 12 government agencies, five in the Air Force, two in the Navy, two in the Army, two in NASA and one in another civilian agency. The 32 firms performing the projects are large corporations in the aerospace and electronics industries, 26 are among the 100 largest performers of government-funded R&D. Five more are smaller but in the same technology. The other one is a large corporation in a basic industry.

The laboratories or engineering facilities in which the projects were performed are located in all regions of the country. Four are in the New England region, 13 in the Middle Atlantic, six in the South and Southwest, four in the Middle West and ten on the West Coast.

The laboratories are primarily engaged in government R&D work, with 23 of them reporting that more than 90 percent of their work was on government contracts, and only two reporting less than 40 percent on government R&D.

The projects ranged in size from $1 million to $60 million with a median of $4 million. The average project duration was 3.4 years and none lasted more than 6 years. Almost all of the projects required advances in the "state of the art" in a technological field such as advanced radar systems, microminiaturization of electronics modules, electronic data processing interfaces with telemetry systems, etc. The projects studied are more developmental than fundamental research.

Measures of Project Performance

It is presently impossible to compare the technical performance of different projects by any objective measures. In one instance, speed may be the primary technical objective of a system (missile, airplane, etc.), while in another case range is most critical. In an electronics system reliability or maintainability may be the chief goal. Consequently the measures of successful technical performance used in this study are expert judgments by the most fully informed individuals (cf. Peck and Scherer, 1962).

Success ratings were obtained independently from the project manager, the laboratory manager, the government contract administrator and the technical monitor. The ratings were on a scale from one to nine, with one representing an outstanding success and nine signifying a failure (in some relative sense, since no project in this study achieved the absolute failure of being cancelled before completion). All except one of the ratings fell in the range of one to five, within which there was a symmetrical distribution with the mode at three.

The measure of performance used in this study is the average of the ratings provided by the project manager, the government technical monitor, plus a constant term to account for the fact that project managers were consistently more optimistic than technical monitors, Table I contains the resulting distribution of technical performance scores. The higher the absolute score, the less well the project did technically.[1]

---

[1] Information on cost and schedule changes was gathered from the project (Footnote cont'd on next page.)

TABLE I

DISTRIBUTION OF TECHNICAL PERFORMANCE SCORES (N=48)

Technical Performance Score[1]	Frequency
1.2	5
1.7	2
1.8	4
1.9	2
2.2	4
2.4	2
2.8	1
3.6	9
4.1	1
4.3	7
4.6	6
5.0	3
5.6	1
8.8	1

MEDIAN = 3.6

Footnote cont'd from page 5.

manager and contract administrator in the company and from the government contract administrator. Careful cross-checking on the reasons for contract changes made it possible to eliminate those caused by a customer's action, such as a change in scope or specifications, or the unavailability of government test equipment or facilities. Thus only those slippages which were directly attributable to the actions of the contractor firm are included. While the data do not at present include the amount of cost and schedule variances, only those greater than 10 percent are included. On this basis there were 28 overruns and 13 on target or underruns. These results are not unlike those reported by Marshall and Meckling (1962), and Peck and Scherer (1962). The rank correlation between cost and schedule performance was 0.82, so the two are combined to form a single performance measure. For the sample of projects under investigation, technical performance is unrelated to cost and schedule performance.

[1] Technical performance is not significantly related to the dollar size of the contract, nature of end product or % basic, applied or development research necessary to accomplish objectives. It is also unrelated to whether the project was considered a crash program (N=20) or not (N=28).

RESULTS

Type of Contract

One of the initial decisions made by the government (buyer) in the procurement process concerns the number of firms that will be requested to bid. If only one company has the capability necessary to meet the technical requirements, the contract can be awarded as a sole source procurement. Otherwise some form of competitive process is initiated and the contract is awarded to the company that wins[1] this competition.

Of the 43 projects for which data are available 28 awards resulted from some form of competitive procedure, and 15 from sole source procurement. Sole source contracts have a mean performance score of 2.80 while the rest have a mean performance score of 3.80. In other words, sole source contractors do significantly better[2] technically than contractors who were selected by some form of competitive procedure.[3] In addition, if one accepts any performance score below the median (2.8 or lower) as being highly successful, (see Table I) 53% of sole source contracts would be judged as highly successful while only 28% of the remainder would fall into this category.

---

[1] See Roberts (1964) for a comparison between the formal process and the actual process by which the government buys research.

[2] Mann-Whitney U-Test, $p < .04$

[3] It should be remembered that the ranking scheme used to measure performance leads to a situation where the lower the absolute score the better the project was judged to be technically.

An attempt was made with the data available to explain why a contract was awarded as sole source. No relationships were found between type of contract and such factors as the number of years a laboratory spent in the technologies required by the project or the laboratory's prior experience relative to others in the field. (The latter was measured by asking the laboratory manager for his subjective estimate and more than 75% of all respondents said they had much more experience than others in the field!) Data were not available concerning the factors considered by the government in their decision to contract sole source in the first place. The available data do not permit an analysis of the weight given to the technical aspects of the competitive proposals relative to other factors.

Subcontract Activity

The next decision examined concerned the percent (on a dollar basis) of total project effort which was subcontracted outside of the organization. Any work done in other parts of the same organization (e.g. another laboratory) or the purchase of off-the-shelf hardware items was not included.

Referring to Table II, it can be seen that in 8 projects, no work was subcontracted while in 2 projects more than 50% of the effort was subcontracted. The median amount subcontracted was 15 percent. When percent effort subcontracted is correlated with technical

TABLE II

DISTRIBUTION OF % OF SUBCONTRACTED (EXCLUDING THE PURCHASE OF OFF-THE-SHELF HARDWARE)

% Subcontracted	Frequency
00%	8
≥ 00 < 10%	9
≥ 10 < 20%	11
≥ 20 < 30%	5
≥ 30 < 50%	6
≥ 50 %	2

performance, it is found that the more work done outside, the less well the project did technically.[1]

Allen (1966) has found that utilization of outside vs. inside sources of information in the performance of research contracts is associated with lower rated technical solutions. This does not mean that outside sources (e.g. consultants) cause poor performance. More likely, as Allen points out, it probably reflects the fact that the organization lacked the technical capability to do the job in the first place. Granted, in our sample, hardware of some sort rather than ideas is the commodity being sought from outside sources. However, it seems reasonable to assume that a similar lack of in-house capability leads an organization to subcontract and for reasons as yet unexplained, such behavior is strongly associated with poorer technical performance.[2]

The next factor examined within the area of subcontract activity was the nature of the restrictions placed upon a contractor's choice of subcontractors. Four alternatives were presented: no restrictions, Small Business Administration, customer approval required, or higher company approval required. If for any of the items a contractor subcontracted, customer and/or higher company approval

---

[1] Kendall Tau = -0.29 ($p < .006$, N=41). In this and all subsequent correlations the performance scale has been reversed so that a positive correlation is more easily interpreted.

In addition, percent effort subcontract and type of contract (sole source vs. competitive) are unrelated suggesting that these factors influence performance independently.

[2] There are difficulties inherent in having to monitor subcontract activity which could result in cost or schedule slippages but no such effects were found in this study.

was checked as being relevant this was called restrictions. Those cases where the contractor checked no restrictions and/or Small Business Administration[1] as being relevant for all of the items subcontracted were classified as no restrictions. The distinction then is between complete freedom from any higher level control vs. the existence (complete or partial) of some formal higher-level approval mechanism.

There were 33 projects that had any subcontracting (See Table II) and data concerning the nature of restrictions on choice of subcontractors were available for 24 of these. When technical performance is correlated with the nature of restrictions, the following results emerge:

	Mean Performance
No Restrictions (N=12)	4.2
Restrictions (N=12)	3.0

From this it can be concluded that the existence of some formal higher-level approval mechanism is strongly associated[2] with better technical performance. Furthermore, when the relationship between

---

[1] The assumption here is that reasons other than technical ability underlay the sources suggested by the Small Business Administration.

[2] Mann-Whitney U-Test $p < .02$

"percent subcontract" and "nature of restrictions" is examined, the following results emerge:

	$\geq$15% Subcontract	$<$15% Subcontract	
No Restrictions	7	5	$X^2 = 0.17$
Restrictions	5	7	$p < .70$

In other words, a high degree of subcontract activity[1] and a lack of any formal review in the choice of subcontractors appear to have independent[2] and detrimental effects on technical performance.

Concerning choice of subcontractors, it may be that within the customer organization, the cognizant individuals have had more experience with a larger number of subcontractors and are therefore in a better position to judge a subcontractor's capacity to do a superior technical job. In the cases where there were no restrictions or only the marginal constraints imposed by the Small Business Administration, other less relevant criteria may have entered into the choice of subcontractors to the detriment of technical performance.

Initial Estimates

The next factor to be considered were certain characteristics of the initial cost, schedule, and technical estimates made by the

---

[1] Due to the reduced sample size, the relationship between "% subcontract" and technical performance was recomputed and the results were the same as those presented earlier.

[2] Both of these factors are unrelated to the type of contract (sole source vs. competitive).

contractor proposal team. The rationale here was that using a particular scheme, such as PERT, to schedule a project initially might force a closer look at technical objectives and thereby influence final technical performance.

No significant differences in technical performance were found to be associated with the possession of additional technical information (other than that included in the RFP), the using of PERT or PERT cost vs. other methods of scheduling the project, or the level of detail[1] used in making initial cost and schedule estimates.

The only question analyzed thus far which very strongly differentiated in terms of technical performance was the following: Did you include a safety factor in your initial cost and schedule estimates? For 15 projects where the project manager (who was in virtually all cases also the proposal manager) answered yes to this question, the technical performance was 2.80. For the 20 projects in which the response was no, technical performance was 4.0. The inclusion of a safety factor is significantly[2] related to superior technical performance.[3] In terms of the arbitrary definition of "highly successful" projects discussed earlier, 56% of the Yes group and 30% of the No group would be classified as highly successful.

---

[1] More than 6 milestones was considered "specific" while fewer than 6 milestones, total effort, and annual effort were considered "not specific."

[2] Mann-Whitney U-Test, $p < .01$

[3] As might be expected the inclusion of a safety factor is strongly associated ($X^2=5.4$ $p < .02$) with the non-occurrance of an overrun. Again, technical performance and cost/schedule performance are unrelated.

It may be that an organization which was initially very optimistic about its technical proposal felt it could afford to build a safety factor into its cost and schedule estimates. The high resulting technical performance could, in a sense, mean that initial optimism was realistic. This possibility is mitigated somewhat, however, by the fact that no relationship was found between the inclusion of a safety factor and being a sole source contractor.[1]

From another point of view, building a safety factor into initial cost and schedule estimates may permit the contractor (particularly the project manager) to focus more of his efforts on the technical job at hand. Since he knows he has a cushion, he no longer has to worry on a day-to-day basis about running out of funds. Here, timing may be a very important factor. A cushion or backlog of dollars may be critically important in the early phases of a project effort.[2] On the other hand, extra time and money across the life of a project may stimulate the contractor to do that "little bit extra" to transform an acceptable job into an excellent job.

Project Team Characteristics

One of the most critical decisions an organization makes before beginning work on a project concerns the selection of project personnel. Project managers were asked the following questions:

---

[1] % Subcontract and nature of restrictions were also found to be unrelated to the inclusion of a safety factor.

[2] See Roberts (1964) for a fuller discussion of a similar point.

How many *key* people who worked on this project were chosen *primarily* on the basis of each of the following criteria; availability, general capability in the area, past association with a similar task, or specialized talent?

What percent of the remaining project personnel were chosen on the basis of each of these same criteria?

The term *key* people was specifically left undefined since it was believed to be a term with which project managers were very familar. When the interviewer was asked what was meant by the term (very few project managers asked the question) the response was: Someone who can really make a project go; if he (a key man) were transferred, the project would feel his loss.

Summing across the four criteria yields the project manager's estimate of the absolute number of key people who worked on the project. The range was 2-60 with a median of 10 key people.[1] A strong positive correlation[2] was found between # key people and technical performance; *the more key people assigned to a project, the better the project did technically*. As one might expect, the # of key people is positivily correlated[3] with the # of full-time professionals working on the project. In addition, within this subsample of the total sample, a moderate relationship[4] exists between technical performance and the # full-time professionals.

---

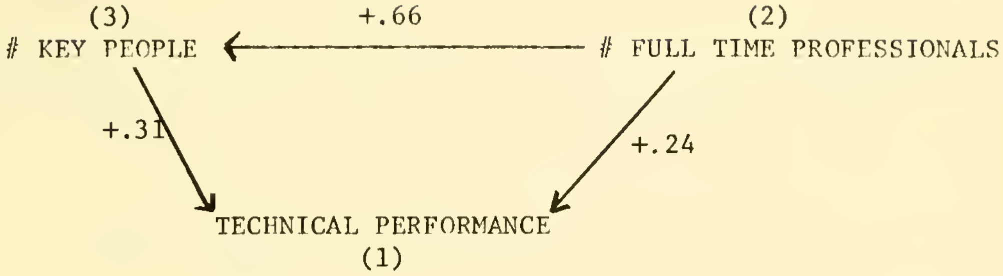
[1] The project with 60 key people had over 200 full-time professionals

[2] Kendall $T=0.31$, $N=34$, $p<.01$

[3] Kendall $T=0.66$, $N=34$, $P<.01$

[4] Kendall $T=0.24$, $N=34$, $p<.07$

These relationships can be summarized in a three variable model:



Utilizing the method of partial correlations, it can be shown that the correlation between # full-time professionals and technical performance disappears when one controls for (eliminates the effect of) the number of key people.[1] The correlation between # key people and performance drops only moderately when one controls for # full-time professionals.[2] In other words, *the number of full-time professionals influences technical performance indirectly by increasing the likelihood that a large # of key people will be working on the project and it is the # of key people which directly affects technical performance.*[3]

Turning now to the criteria for selection of key people, no relationships are found between technical performance and the number of key people chosen primarily on the basis of availability, general

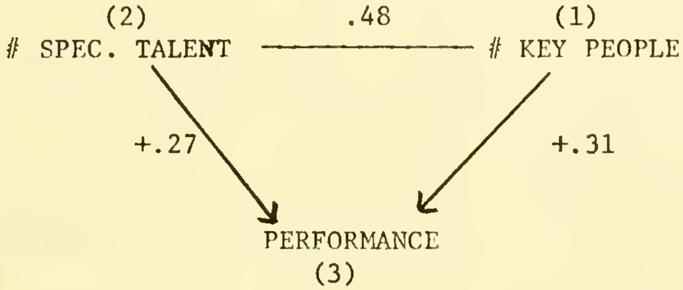
---

[1] T 1,2.3 = 0.04, 88% reduction

[2] T 1,3.2 = 0.21, 32% reduction

[3] No relationship is found between performance and the *percent* of full-time professionals considered to be key people.

capability and past association.[1] The number of key people chosen by specialized talent was however, significantly related to technical performance[2] as well as to the absolute number of key people.[3] These relationships can be summarized in a three variable model:



Again, using the method of partial correlations, it can be seen that neither of the direct correlations with performance disappears completely as was the case in the prior analysis.[4] It would appear that the # of key people and # of key people chosen by specialized talent have a moderate effect upon technical performance independent of the relationship between them.[5]

---

[1] For 11 of 34 projects, none of the key people were chosen on the basis of past association. For those in which any key people were chosen on this basis, the correlation between # key people and performance is T=0.32 ($p<.02$, N=23).

[2] Kendall T = 0.27, N=34, $p<.03$

[3] Kendall T = 0.48, N=34, $P<.01$

[4] T 1,3.2 = 0.22; T 2,3.1 = 0.14

[5] None of the "key people" variables are related to type of contract (sole source vs. competitive), % of subcontract, restrictions on choice of subcontractors, or the inclusion of a safety factor in cost/schedule estimates.

Concerning the criteria of selection of other project personnel, no relationship is found between technical performance and the percent of other project personnel chosen on the basis of availability, specialized talent, or general capability. The only suggestion of a relationship appears between percent chosen by past association and technical performance.[1] Analysis of more complex relationships is necessary before anything further can be said in this area. It may be, for example, that # of full-time professionals available (and used) increases the liklihood that a large number of key people will be available which in turn makes selection by specialized talent more feasible leading to higher technical performance.[2]

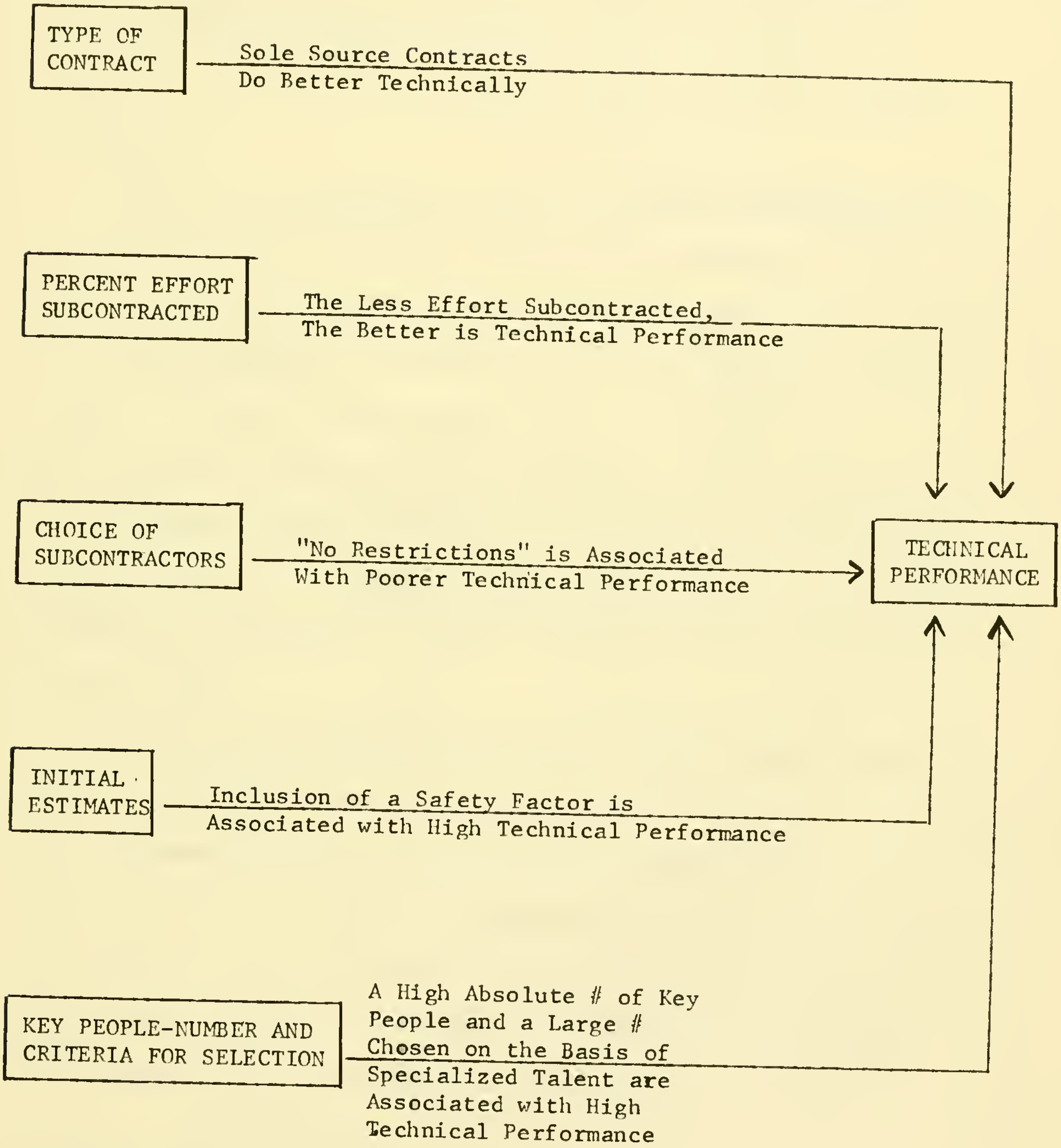
---

[1] Kendall $T = 0.22$, $N=34$, $p < .06$

[2] Data concerning the project manager (education, experience, etc.) have been eliminated from consideration here and will form the subject of a future paper.

Summary

The findings presented in this paper can be summarized graphically in the following manner:



Sole Source Contracts Do Better Technically

The Less Effort Subcontracted, The Better is Technical Performance

"No Restrictions" is Associated With Poorer Technical Performance

Inclusion of a Safety Factor is Associated with High Technical Performance

A High Absolute # of Key People and a Large # Chosen on the Basis of Specialized Talent are Associated with High Technical Performance

As pointed out earlier, data are not presently available to explain why, for example, a particular contract was awarded on a sole source basis or what it is about having to subcontract a large percent of the total effort which leads to poorer technical performance.

Answers to these questions could be extremely important when one considers the time frame of the variables discussed. All of them represent the result of decisions made by the government and/or the contractor prior to the start of any full scale work on the project. A better understanding of why such decisions seem to effect technical performance could, for example, lead to revisions in contractor selection procedures. In the case of the finding concerning the value of including a safety factor in initial estimates, changes might be made in the manner ("how much when") of funding project efforts.

The focus in this paper has been on the relationship between certain inputs and outputs - the project has been viewed as a black box. This is not meant to imply that other factors which occur during the life of a project are unimportant with respect to technical performance.[1] What is suggested is that more attention could be paid to the impact of initial conditions over which both the government and the buyer may have considerably more control.

---

[1] Future papers will relate technical performance to such factors as the project manager (education, past experience, patterns of effort allocation), project priority, customer monitoring of project (amount and type), and other factors which occur during the life of a project.

REFERENCES

Allen, T. J., "The Differential Performance of Information Channels in the Transfer of Technology" Working Paper #196-66, Sloan School of Management, M.I.T.

Marquis, D. G., and Straight, D. M. "Organizational Factors In Project Performance" Working Paper #133-65, Sloan School of Management, M.I.T., August, 1965.

Marshall, A. W. and Meckling, W. H. Predictability of the costs, time, and success of development. In *The rate and direction of inventive activity*. Princeton: Princeton Univ. Press, 1962, 461-475.

Peck, M. J. and Scherer, F. M. *The weapons acquisition process: An economic analysis*. Cambridge, Mass.: Harvard Graduate School of Business Administration, 1962, 170-181.

Roberts, E. B. "How the U.S. Buys Research" Working Paper #82-64, Sloan School of Management, M.I.T., August, 1964.

Roberts, E. B. *The Dynamics of Research and Development*. New York, Harper & Row, 1964.

CT 8 70([illegible])

Date Due

APR 22 '77	NOV 2	
JUL 3 '78	NOV. 22 1992	
SEP 18 '78	APR 16 1990	
MAR 14 '80		
ILL		
[illegible] '80		
APR 06 '81		
ILL		
JAN 7 '82 MAY 21		
~~SEP~~		
SEP 23 '82		
10 '82		

Lib-26-67

MIT LIBRARIES
3 9080 003 869 176
187-66

MIT LIBRARIES
3 9080 003 869 192
188-66

MIT LIBRARIES
3 9080 003 900 187
189-66

MIT LIBRARIES
3 9080 003 869 275
191-66

MIT LIBRARIES
3 9080 003 869 226
192-66

MIT LIBRARIES
3 9080 003 900 237
194-66

MIT LIBRARIES
3 9080 003 869 267
195-66